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Electric device comprising phase-change material

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Electric device comprising phase-change material

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The invention relates to an electric device with a body having a resistor comprising a phase-change material. The resistor has an electrical resistance having a first value when the phase-change material is in a first phase and a second value when the phase-change material is in a second phase, the first value being different from the second value.

- 5 The resistor is able to conduct a current for heating of the phase-change material to enable a transition from the first phase to the second phase.

- 10 WO-A 00/57,498 discloses an embodiment of an electric device comprising a phase-change material.

The known device comprises a resistor comprising of a phase-change material, which has approximately a composition of  $\text{Sb}_2\text{Te}_5\text{Ge}_2$ . It may be, e.g.,  $\text{Sb}_{22}\text{Te}_{56}\text{Ge}_{22}$  or  $\text{Sb}_{29}\text{Te}_{57}\text{Ge}_{14}$ . The phase-change material is able to be in a first phase, which may be, e.g., crystalline, and it is able to be in a second phase, which may be, e.g., amorphous.

- 15 Alternatively, one or both of the first phase and the second phase may be partly amorphous and partly crystalline, provided that the resistor with the phase-change material in the first phase and the resistor with the phase-change material in the second phase have different values of the electrical resistance.

- 20 The resistor is electrically connected to a first conductor and a second conductor such that the value of the electrical resistance can be measured. The first conductor and the second conductor may comprise, e.g., one or more of the following materials: titanium, titanium nitride, titanium aluminum nitride, titanium carbon nitride, titanium silicon, molybdenum, carbon, tungsten, and titanium tungsten.

- 25 The resistor, the first conductor and the second conductor are able to conduct an electrical current which via heating enables transitions of the phase-change material between the first phase and the second phase. Heating by a sufficiently strong current causes melting of the phase-change material and enables a transition from a phase with a relatively good electrical conductivity such as a crystalline phase or a mainly crystalline phase, to a phase with a relatively poor electrical conductivity such as an amorphous phase or a mainly

amorphous phase. The heating is achieved by the resistance of the first conductor, the second conductor, the resistor itself and the contact resistance between these elements. Which of these resistances contributes most to the Joule heating depends in general on the materials and shapes of these elements. The heating ends when switching off the current. In case of a  
5 short heating period in combination with a sufficiently fast-cooling environment, the phase-change material then cools down and arranges in a more amorphous order.

When inducing a transition from a phase with a relatively low electrical conductivity to a phase with a relatively high electrical conductivity, the heating is initially counteracted by the poor conductivity, which limits the current conducted through the phase-  
10 change material. It is believed that by applying a sufficient voltage, the so called break down voltage, across the resistor it is possible to locally induce an electrical breakdown in the phase-change material, which leads to a high local current density. The corresponding resistive heating is then sufficient to increase the temperature of the phase-change material above its crystallization temperature thereby enabling the phase transition from the  
15 amorphous phase to the crystalline phase.

The known electric device can be used as a resistor with an electrically adjustable resistance. This type of device may be used in all types of circuits and integrated circuits which require a resistor with a resistance switchable between a first value and a second value.

20 The known electric device is particularly suited for use as electrically writable and erasable memory cell, which carries information encrypted in the value of the electrical resistance. The memory cell is assigned, e.g., a "0" when the resistance is relatively low and a "1" when the resistance is relatively high. The resistance may be easily measured by supplying a voltage across the resistor and measuring the corresponding current. The memory  
25 element can be written and erased by inducing a transition from a first phase to a second phase as described above.

It is a disadvantage of the known electric device that the switching time from the amorphous phase to the crystalline phase is relatively long. This limits the rate at which the resistor value can be set.

30

It is an object of the invention to provide an electric device comprising a phase-change material which has a relatively short switching time from the amorphous phase to the crystalline phase.

The invention is defined by the independent claims. The dependent claims define advantageous embodiments.

The invention is based on the insight that the class of phase-change materials used in the claimed invention, which are compositions of formula  $Sb_aTe_bX_{100-(a+b)}$  with  $a$ ,  $b$  and  $100-(a+b)$  denoting atomic percentages satisfying  $1 \leq a/b \leq 8$  and  $4 \leq 100-(a+b) \leq 22$ , and  $X$  being one or more elements selected from Ge, In, Ag, Ga and Zn, has a different crystal growth mechanism than the known phase-change materials. In the known phase-change materials the phase transition from the amorphous phase to the crystalline phase takes place by nucleation, i.e. the crystallization starts from several randomly distributed points within the amorphous phase. The crystallization time in the known device is therefore independent of the volume of the amorphous phase. It is restricted by the nucleation time which is in the order of 50 ns for the known phase-change materials.

In contrast to this, the electric device according to the invention comprises a phase-change material which is a so-called fast-growth material. In fast-growth materials the crystalline phase grows at a high speed, the so-called crystallization speed, from the interface between the amorphous phase and the crystalline phase. In general, the crystallization speed depends on the temperature. Here and below, crystallization speed refers to the temperature averaged, effective crystallization speed. For these materials the crystallization time depends on the volume of the amorphous phase. The electric device according to the invention comprises a phase-change material with crystallization speed of at least 1 m/s. The amorphous phase-change material of the known electric device has dimensions in the order of magnitude of 10 to 20 nm. Applying the phase-change material according to the invention in such a device results in a switching time of 10 to 20 ns or less. In case of multi-level recording the amorphous volumes vary in size and require therefore different crystallization times.

Another advantage of the electric device according to the invention is that the crystallization speed and the stability of the amorphous phase, which influences the archival life stability, can be controlled independently by tuning the Sb/Te ratio  $a/b$  and by tuning the amount and the composition of element  $X$ . The crystallization speed scales approximately linearly with the ratio  $a/b$ . Preferably, the ratio  $a/b$  is smaller than or equal to 4.

The electric device according to the invention has the additional advantage that the break down voltage required for switching from the high resistive amorphous state to the low resistive crystalline phase is lower than that of the known electric device. This is particularly advantageous when using advanced transistors to switch the electric device

because the advanced transistors have smaller dimensions and are therefore able to provide only a relatively small voltage. The inventors have established that the break down voltage scales approximately with the band gap of the phase-change material and that the band gap decreases with increasing Sb amount.

5           A further advantage of the electric device according to the invention resides in the fact that the resistivity of the crystalline phase is lower than that in the known electric device. Therefore, the ohmic losses in the crystalline phase are smaller than those in the known electric device allowing for saving power. Moreover, the contact resistance between the first conductor and the phase-change material, and between the second conductor and the  
10 phase-change material in the electric device according to the invention is lower than that in the known electric device. This allows one to use a smaller first contact area and/or second contact area which for the electric device according to the invention results in a shorter switching time between the amorphous phase and the crystalline phase, and in a lower switching power.

15           In the electric device according to the invention a smaller amount of Te is used than in the known electric device. This has the advantage that the phase-change material is less reactive which improves the stability of the electric device. In addition the phase-change material of the electric device according to the invention has a relatively low vapor pressure due to the reduced Te amount which allows for higher processing temperatures.

20           It is advantageous if the element X comprises Ge. An electric device comprising a phase-change material comprising Ge has the advantage that the crystallization temperature is relatively high and therefore, the amorphous phase is stable up to relatively high temperatures.

          In an embodiment the phase-change material comprises more than 10 % and  
25 less than 22 % Ge. In this case the crystallization temperature of the phase-change material is between 180 and 250 degrees Celsius. When the crystallization temperature is lower than 180 degrees Celsius, the stability of the amorphous phase may be insufficient, in particular when the electric device may be subjected to relatively high temperatures. When the crystallization temperature is higher than 200 degrees Celsius, a relatively high switching power is required  
30 to induce a phase transition from the amorphous phase to the crystalline phase.

          It is advantageous if the first contact area is smaller than or equal to the second contact area, the first contact area having a characteristic dimension  $d$ ,  $6 \cdot a/b$  being smaller than  $d$  where  $d$  is in nm. This embodiment of the invention is based on the following insight: in order to be able to perform a phase transition from the crystalline phase to the amorphous

phase it is required that the cooling time, i.e. the time in which the phase-change material cools down to a temperature below the crystallization temperature is smaller than the crystallization time, i.e. the time required for a transition from the amorphous phase back to the crystalline phase. If this condition is not met, the melted amorphous material re-

5 crystallizes during cooling down, resulting in the same phase as before the heating, i.e. the phase transition from the crystalline phase to the amorphous phase is not possible.

For the phase-change material of the electric device according to the invention the crystallization starts at the interface between the amorphous phase and the crystalline phase. Therefore, the crystallization time is given by the characteristic dimension of the

10 amorphous volume divided by the crystallization speed. Here, the characteristic dimension is the largest distance between the point which is the last to crystallize and the border between the amorphous phase and the crystalline phase at the start of the phase transition. This dimension can be approximated by the characteristic dimension of the first contact area provided that the first contact area is not larger than the second contact area.

15 The inventors have determined the cooling time from simulations and the crystallization speed as function of the composition of the phase-change material from experiments. Using the results of these simulations and measurements combined with the above described criterion it can be shown that  $6 \cdot a/b$  has to be smaller than  $d$  where  $d$  is in nm in order to prevent complete re-crystallization during cooling down of the amorphous phase.

20 In some cases the characteristic dimension of the amorphous phase change volume extends beyond the first contact area, the amorphous phase having approximately twice the size of the first contact area. The requirement can then be relaxed to  $3 \cdot a/b$  being smaller than  $d$  where  $d$  is in nm. In this case a first contact area with a two times smaller surface area can be used.

25 In an embodiment the phase-change material of the resistor is in direct contact with a crystallization layer having a crystal structure. This crystallization layer is advantageous in situations where a volume with the amorphous phase has a surface area which is in direct contact with a material different from the phase-change material. When performing a phase transition from the amorphous phase to the crystalline phase, the phase-

30 change material of the electric device according to the invention starts growing from the ~~interface~~ between the crystalline phase and the amorphous phase. At the surface area which is in direct contact with a material being different from the phase-change material, the crystallization is therefore delayed, leading to a relatively long crystallization time. By introducing a crystallization layer having a crystal structure the crystal growth at the surface

area can be expedited. Preferably, the crystal structure of the crystallization layer is similar to that of the phase-change material.

It is advantageous if the crystallization layer has a thickness smaller than 100 nm. The crystallization layer is a potential heat sink, in particular due to its crystal structure.

5 In order to limit the corresponding heat flow out of the phase-change material during heating for promoting a phase transition, the crystallization layer should be relatively thin.

Crystallization layers with a thickness larger than 100 nm lead to a relatively large heat flow out of the phase-change material. Preferably, the thickness of the crystallization layer is smaller than 50 nm. It is further advantageous to select a crystallization layer with a relatively

10 low thermal conductivity such that the heat flow out of the phase-change layer is further restricted.

Preferably, the crystallization layer is in direct contact with the first contact area and/or in direct contact with the second contact area because the phase-change material is often amorphous in the vicinity of the first contact area and/or the second contact area. It is

15 often advantageous if the crystallization layer is electrically conducting and electrically connecting the first contact area and the second contact area. In this case the crystallization layer constitutes an electrical bypass arranged in parallel to the phase-change material. The crystallization layer is then able to conduct a current which can be used to indirectly heat the phase-change material for promoting the transition from the first phase to the second phase.

20 Preferably, a melting temperature of the crystallization layer is larger than a melting temperature of the phase-change material. Preferably, the crystallization layer is chemically relatively stable to reduce the chance that the material of the crystallization layer mixes with the phase-change material.

The crystallization layer is particularly advantageous if multi bits are stored in

25 one electric device leading to an increased storage capacity. In this case the volume of the phase-change material undergoing the phase transition determines the resistance of the cell and hence which bit is stored. It is then often convenient to use a volume undergoing the phase transition which extends beyond the first contact area and/or the second contact area. In particular in these cases the crystallization layer is beneficial.

30 In an embodiment of the electric device according to the invention the first conductor, the second conductor, the resistor and the layer constitute a memory element, and the body comprises an array of memory cells, each memory cell comprising a respective memory element and a respective selection device, and a grid of selection lines, each memory

cell being individually accessible via the respective selection lines connected to the respective selection device.

Such an electric device can be used as a non-volatile, electrically writable, electrically readable and electrically erasable memory. Because each memory cell comprises a selection device, individual memory elements can be conveniently selected for reading, i.e. for measuring the value of the electrical resistance, and for writing and erasing, i.e. for inducing a transition from a first phase to a second phase.

The memory elements of the present invention may be electrically coupled to selection devices and to selection lines in order to form a memory array. The selection devices permit each discrete memory cell to be read and written without interfering with information stored in adjacent or remote memory cells of the array. Generally, the present invention is not limited to the use of any specific type of selection device. Examples of selection devices include field-effect transistors, bipolar junction transistors, and diodes such as known from, e.g., WO-A 97/07550. Examples of field-effect transistors include JFET and metal oxide semiconductor field effect transistor (MOSFET) such as known from, e.g., WO-A 00/39028. Examples of MOSFET include NMOS transistors and PMOS transistors. Furthermore NMOS and PMOS may even be formed on the same chip for CMOS technologies.

Usually, such types of electric devices are as compact as possible which implies that the mutual distance between adjacent resistors is small. In these electric devices comprising a dielectric material according to the invention the cross write is reduced. Cross-write is the phenomenon that during writing of a particular memory cell the phase-change material of an adjacent memory cell is altered, potentially leading to an erroneous value of the resistance in the adjacent memory cell.

In one embodiment the selection device comprises a MOSFET having a source region, a drain region and a gate region, and the grid of selection lines comprises N first selection lines, M second selection lines, N and M being integers, and an output line, the first conductor of each memory element being electrically connected to a first region selected from the source region and the drain region of the corresponding metal oxide semiconductor field effect transistor, the second conductor of each memory element being electrically connected to the output line, a second region of the corresponding metal oxide semiconductor field effect transistor which is selected from the source region and the drain region and which is free from the first region, being electrically connected to one of the N first selection lines, the gate region being electrically connected to one of the M second selection lines.

In this type of device the resistor can be conveniently integrated with the selection device.

5           These and other aspects of the electric device according to the invention will be further elucidated and described with reference to the drawings, in which:

Fig. 1 is a cross section of an embodiment of the electric device;

Figs. 2A and 2B are plots of the switching from the amorphous phase to crystalline phase, and from the crystalline phase to amorphous phase, respectively;

10           Fig. 3 is a plot of the current as function of the applied voltage when switching from the amorphous phase to crystalline phase;

Fig. 4 is a plot of the crystallization speed for various compositions; and

Fig. 5 is a cross section of another embodiment of the electric device, and by means of some tables, in which:

15           Table 1 shows embodiments of the phase-change material used in the electric device; and

Table 2 shows minimum characteristic dimensions for the phase-change materials of Table 1.

20           The Figures are not drawn to scale. In general, identical components are denoted by the same reference numerals.

The electric device 1, shown in Fig. 1, has a body 2 which comprises a substrate 10 which may comprise, e.g., a single crystal p-doped silicon semiconductor wafer.

25   On a main surface of the substrate 10 a resistor 7 is embedded in a dielectric 13, e.g., silicon oxide. The resistor 7 comprises a phase-change material changeable between a first phase and a second phase. The phase-change material of the electric device 1 comprises Sb, Te and X being one or more elements selected from Ge, In, Ag, Ga and Zn in the ratio  $Sb_aTe_bX_{100-(a+b)}$ , where a, b and  $100-(a+b)$  denote atomic percentages with  $1 \leq a/b \leq 8$  and  $4 \leq 100-(a+b) \leq$

30   22. The phase-change material may be, e.g.,  $Sb_{72}Te_{20}Ge_8$ , other embodiments of the phase-change material will be described below. The resistor 7 has a surface with a first contact area 5 and a second contact area 6, and an electrical resistance R between these two contact areas. The electrical resistance has a first value when the phase-change material is in the first phase and a second value when the phase-change material is in the second phase.

The body 2 further comprises a first conductor 3 of titaniumdisilicide ( $\text{TiSi}_2$ ) which is electrically connected to the first contact area 5, and a second conductor 4 of titanium nitride ( $\text{TiN}$ ), which is electrically connected to the second contact area 6. The first conductor 3 and the second conductor 4 are connected to metal lines 8 and 9, respectively.

5 The metal lines 8 and 9 comprise tungsten and have contact pads 11 and 12, respectively, which allow for conducting a current through the first conductor 3, the second conductor 4 and the resistor 7 for heating of the phase-change material to enable a transition from the first phase to the second phase, as is described in more detail above.

To characterize the switching behavior of the electric device 1, a voltage U  
10 was provided between contact pads 11 and 12, and the current I flowing due to this voltage was measured. Typical results of such measurements are shown in Figs. 2A and 2B, where the solid line and the dotted line denote the voltage U and current I, respectively.

For the measurement of Fig. 2A the resistor 7 was initially at  $t=0$  in the amorphous phase. At  $t=50$  ns a first voltage pulse of approximately 0.15 V was applied  
15 which did not lead to any significant current I during this voltage pulse. This demonstrates that the phase-change material of the resistor 7 was indeed in the high resistive amorphous state. At  $t=200$  ns a second voltage pulse of approximately 0.5 V was applied which did lead to a current I of 300  $\mu\text{A}$  during this voltage pulse. Here, the supplied voltage was larger than the break down voltage and therefore, a significant current I is detected. At  $t=370$  ns a third  
20 voltage pulse substantially identical to the first voltage pulse was applied which does lead to a detectable current I of approximately 80  $\mu\text{A}$ . This shows that the phase-change material is in a more crystalline phase with a lower resistance during the third voltage pulse. The current conducted through the resistor 7 during the second voltage pulse was sufficient to heat the phase-change material for promoting the transition from the amorphous phase to the  
25 crystalline phase.

For the measurement of Fig. 2B the resistor 7 was initially at  $t=0$  in the crystalline phase. At  $t=50$  ns a fourth voltage pulse substantially identical to the first voltage pulse was applied which does lead to a detectable current I of approximately 80  $\mu\text{A}$ . This shows that the phase-change material is in a more crystalline phase with a lower resistance  
30 analogous to the time of the third voltage pulse. At  $t=200$  ns a fifth voltage pulse of approximately 0.8 V was applied which does lead to a current I of 700  $\mu\text{A}$  during this voltage pulse. Here, the supplied voltage was large enough to melt the crystalline phase and the cooling down of the molten amorphous phase was fast enough to freeze the phase-change

material in an amorphous phase. As a result, a sixth voltage pulse substantially identical to the first voltage pulse provided at  $t=370$  ns does no longer lead to a detectable current  $I$ .

The voltage pulses each had a duration of 10 ns. The results of Fig. 2A and 2B show that the electric device 1 according to the invention can be switched from the amorphous phase to the crystalline phase, and from the crystalline phase to the amorphous phase with a switching time of at most 10 ns which is approximately a factor of 5 faster than that of the known electrical device.

The electrical break down behavior of the electric device 1 according to the invention and that of the known electric device are compared in Fig. 3. For both devices the current  $I$  is measured as function of the applied voltage  $U$ . The measurements were started with the phase-change material being in the amorphous phase. A voltage of 0.1 V was applied to the devices which resulted in a relatively small current  $I$ . Subsequently the voltage was increased and for each voltage the corresponding current was measured.

In the electric device 1 according to the invention the break down occurred approximately at  $U_{bd}=0.45$  V leading to a largely increased current  $I$ . In the known electric device the break down occurred approximately at  $U_{bd}=0.6$  V. Further increasing the voltage  $U$  resulted in a linearly increasing current  $I$ . The corresponding differential resistance for voltages  $U$  larger than the break down voltage  $U_{bd}$  is denoted  $R_{bd}$ . The result shown in Fig. 3 illustrates that the electric device 1 according to the invention has a smaller break down voltage than the known electric device.

The crystallization speed of the phase-change material used in the electric device 1 is shown in Fig. 4. The crystallization speed is 1 m/s or larger and it increases approximately linearly with increasing the amount of Sb with respect to the amount of Te. The phase-change material of the electric device 1 according to the invention comprises Sb and Te in ratio Sb/Te larger than 1 and smaller than 8. Preferably, the ratio is smaller than 4 because for larger ratios the crystallization speed is above approximately 4.5 m/s. In many cases it is then not possible to obtain an amorphous phase because the phase-change material crystallizes before it is cooled down below the crystallization temperature. It is, however, possible to use sophisticated write strategies based on short high-power write pulses and rapid cooling structures to enable the formation of amorphous areas. The phase-change material further comprises 4 to 22 atomic percentage of an element X selected from Ge, In, Ag, Ga and Zn. The element X may comprise one or more of these elements. Examples of the phase-change material are given in Table 1. The crystallization speed of the phase-change

material is above 1 m/s and increasing with increasing the Sb/Te ratio, independent of the choice of the element X and its concentration.

Sb/Te	Ge	In	Ag	Ga
3.6	8			
1.7	15			
1.5	15			
1.7	10			
3.6			8	
3.6				8
5.1				8
3.6		8		
4		5		
4		10		
3.6	6	2		
3.6	2	7		
3.6		4		4
3.3	1			4
3.3	2			3
4.5	11			

- 5 Table 1: Examples of the phase-change material. Ge, In, Ag and Ga denote the atomic percentage of these elements comprised in the phase-change material, Sb/Te denotes the ratio of the atomic percentage of Sb and Te.

In another embodiment, shown in Fig. 5, the electric device 100 is formed in  
 10 body 101 comprising a semiconductor substrate 102 analogous to substrate 10 of Fig. 1. It comprises an N x M array of memory cells which array is identical to that known from WO-A 00/57498, see in particular Fig. 4 of that patent application. Here, N and M are integers, one of which may be zero, resulting in a one-dimensional array. Each memory cell comprises a respective memory element 103 and a respective selection device 104. In the embodiment  
 15 shown in Fig. 5 each memory cell comprises two independent memory elements 103A and 103B. The first conductor 130A, the second conductor 270A, the resistor 250 and the layers 127A and 128 constitute memory element 103A, and the first conductor 130B, the second

conductor 270B, the resistor 250 and the layers 127B and 128 constitute memory element 103B. In other words, the memory elements 103A and 103B share the same resistor 250 and the same layer 128. In another embodiment, not shown, layer 128 is omitted and layer 250 is in direct contact with layer 260. In yet another embodiment, also not shown, layer 127A and/or 127B are omitted.

The resistor 250 comprises one of the phase-change materials described above. It has a surface with first contact areas 132A and 132B, and second contact areas 272A and 272B, respectively. As part of memory element 103A, the resistor 250 has an electrical resistance between the first contact area 132A and the second contact area 272A which has a first value when the phase-change material is in the first phase and a second value when the phase-change material is in the second phase. As part of memory element 103B, the resistor 250 has an electrical resistance between the first contact area 132B and the second contact area 272B which has a first value when the phase-change material is in the first phase and a second value when the phase-change material is in the second phase. In case of a multi-level recording embodiment, the resistance of the path between contact area 132A and 272A can have multiple resistance levels.

The contact areas 132A and 132B are smaller than or equal to the second contact areas 272A and 272B, respectively. The first contact areas 132A and 132B each have a characteristic dimension  $d$ . In one embodiment the atomic percentages  $a$  and  $b$  of Sb and Te, respectively, are chosen such that the ratio  $a/b$  is smaller than  $d/3$  where  $d$  is in nm. For a given ratio  $a/b$  this implies that the minimum characteristic dimension of the first contact area 132 is  $d_{\min,1} = 6 \cdot a/b$  where  $d$  is in nm. Typical values of  $d_{\min,1}$  for various ratios of  $a/b$  are given in Table 2.

When the amorphous volume extends beyond the first contact area, the minimum characteristic dimension of the first contact area 132 can be relaxed to approximately  $d_{\min,2} = 3 \cdot a/b$  where  $d$  is in nm. Typical values are also shown in Table 2.

Sb/Te	$d_{\min,1}$ (nm)	$d_{\min,2}$ (nm)
1.5	9	4.5
1.7	10.2	5.1
3.3	19.8	9.9
3.6	21.6	10.8
4	24	12
4.5	27	13.5
5.1	30.6	15.3

Table 2: Minimum characteristic dimension of an electric device 1 in which the phase-change material does not extend beyond the first contact area 132 and in which it extends to approximately twice the characteristic dimension of the contact area. In the first case the minimum allowable characteristic dimension is  $d_{\min,1}$ , in the latter it is  $d_{\min,2}$ .

The first conductors 130A and 130B are electrically connected to the first contact areas 132A and 132B, respectively. The second conductors 270A and 270B are electrically connected to the second contact areas 272A and 272B, respectively. The first conductor 130A, the second conductor 270A and the resistor 250 are able to conduct a current for heating of the phase-change material to enable a transition from the first phase to the second phase thereby changing the electrical resistance of the first memory element 103A. Analogously, the first conductor 130B, the second conductor 270B and the resistor 250 are able to conduct a current for heating of the phase-change material to enable a transition from the first phase to the second phase thereby changing the electrical resistance of the second memory element 103B.

As shown in the embodiment shown in Fig. 5, a layer 260 of a dielectric material provides for electrical isolation between the resistor 250 and the output line 271 such that the resistor 250 is connected to the output line 271 only via the second conductors 270A and 270B. The dielectric layer 140 electrically isolates the first conductor 130A from the first conductor 130B. A dielectric layer 180 which may comprise borophosphosilicate glass (BPSG) is deposited on top of the electric device 100.

Analogous to the electric device known from WO-A 00/57498, the first conductors 130A and 130B are conductive sidewall spacers, also referred to as conductive spacers, formed along the sidewall surfaces 126S of the dielectric regions 126. The area of

contact between the resistor 250 and the first conductors 130A and 130B are the first contact area 132A and 132B, respectively. Hence, the only electrical coupling between the resistor 250 and the first conductors 130A and 130B is through all or a portion of the first contact area 132A and 132B, respectively. The remainder of the first conductors 130A and 130B is  
5 electrically isolated from the resistor 250 by dielectric layers 126 and 140.

Alternately, the first conductor 130A and/or 130B may be formed as conductive sidewall spacers by conformally depositing one or more contact layers onto the sidewall surface or surfaces of a via hole as known from WO-A 00/57498. The via hole may be round, square, rectangular or irregularly shaped. The conductive sidewall spacers may also  
10 be formed by conformally depositing one or more contact layers onto the sidewall surfaces of a pillar or mesa. The remaining space in the via is filled with a layer of dielectric material.

In the electric device 100, shown in Fig. 5, the phase-change material of the resistor 250 is in direct contact with crystallization layers 127A, 127B and 128, each of which has a crystal structure. It may be a conductor, a semiconductor or a dielectric. It may  
15 comprise, e.g., PbTe, Ag<sub>2</sub>Te, CrTe Pb, Ge and Si. It has a thickness between 2 and 100 nm. The crystallization layer 127A and 127B are in direct contact with the first contact area 132A and 132B, respectively. The crystallization layer 128 is in direct contact with the second contact area 272A and 272B.

The body 101 comprises a grid of selection lines comprising N first selection  
20 lines 190, M second selection lines 120 and an output line 271 such that each memory cell is individually accessible via the respective selection lines 120 and 190 connected to the respective selection device 104. Each of the memory elements 103A and 103B of electric device 100 is electrically coupled to a selection device 104 which is a MOSFET, and more specifically an NMOS transistor. The MOSFET has n-doped source regions 110, n-doped  
25 drain regions 112, and gate regions 118. The source regions 110 and the drain regions 112 may comprise more than one portion of n-doped material, namely a lightly doped n-portion and a more heavily doped n+ portion.

The n-doped source regions 110 and drain regions 112 are separated by channel regions 114. The gate regions 118, formed above the channel regions 114, control  
30 the flow of current from the source regions 110 to the drain regions 112 through the channel regions 114. The gate regions 118, preferably comprise a layer of polysilicon. Separating the gate regions 118 from the channel regions 114 are dielectric regions 116.

Channel stop regions 113 are formed in the n-doped drain regions 112 creating two neighboring, electrically isolated drain regions 112 for separate NMOS transistors.

Generally, the channel stop regions 113 are of a conductivity type opposite that of the source and drain regions 110, 112. In the NMOS embodiment shown, the channel stop regions 113 comprises p-doped silicon.

5 Formed above the gate regions 118 are selection lines 120 which preferably comprise a layer of tungsten silicide. Selection lines 120 are used to deliver the electrical signal to the gate regions 118. Formed above the selection lines 120 are the dielectric regions 122 which electrically insulate the selection lines 120 from neighboring regions of the electric device 100. The stack of layers 116, 118, 120 are collectively referred to as the gate stacks. Dielectric regions 126 are formed on the sidewall surfaces of the gate stacks.

10 Selection lines 190 are formed on top of the upper insulation regions 180. The selection lines 190 may be formed from a conductive material such as aluminum or copper. Tungsten plugs 144 electrically connect the selection lines 190 to the drain regions 110. It is noted that in the particular embodiment shown in Figure 5, two NMOS transistors share each of the tungsten plugs 144. A layer of titanium silicide (not shown) may be formed on the  
15 surface of the silicon substrate to improve the conductivity between the substrate 102 and the conductive sidewall spacers 130A and 130B as well as between the substrate 102 and the conductive plugs 144. The conductive plugs 144 are electrically insulated from the gate stacks by dielectric layers 126.

The first conductors 130A and 130B of memory element 103A and 103B,  
20 respectively, are electrically connected to a first region selected from the source region 110 and the drain region 112 of the corresponding metal oxide semiconductor field effect transistor. In the embodiment of Fig. 5 the first region is the drain region 112. The second conductor 270 of each memory element 103A and 103B is electrically connected to the output line 271, which may comprise, e.g., the same material as the second conductor 270. A  
25 second region of the corresponding metal oxide semiconductor field effect transistor, which is selected from the source region 110 and the drain region 112 and which is free from the first region, is electrically connected to one of the N first selection lines 190. The gate region 116 is electrically connected to one of the M second selection lines 120.

In summary, the electric device 1, 100 has a body 2, 101 with a resistor 7, 250  
30 comprising of a phase-change material able to be in a first phase and able to be in a second phase. The resistor 7, 250 has a surface with a first contact area 5, 132 and a second contact area 6, 272, and has an electrical resistance between them. The electrical resistance has a first value when the phase-change material is in the first phase and a second value when the phase-change material is in the second phase. The second value is different from the first

value. The phase-change material comprises Sb, Te and X being one or more elements selected from Ge, In, Ag, Ga and Zn in the ratio  $Sb_aTe_bX_{100-(a+b)}$ . Here, a, b and  $100-(a+b)$  denoting atomic percentages with  $1 \leq a/b \leq 8$  and  $4 \leq 100-(a+b) \leq 22$ . The electric device 1, 100 further comprises a first conductor 3, 130 electrically connected to the first contact area 5, 132, and a second conductor 4, 270 electrically connected to the second contact area 6, 272. The first conductor 3, 130, the second conductor 4, 270 and the resistor 7, 250 are able to conduct a current for heating of the phase-change material to enable a transition from the first phase to the second phase.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word "comprising" does not exclude the presence of other elements or steps than those listed in a claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements.

## CLAIMS:

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1. An electric device with a body having a resistor comprising a phase-change material being changeable between a first phase and a second phase, the resistor having a first contact area and a second contact area, the resistor having an electrical resistance between the first contact area and the second contact area, the electrical resistance depending upon the phase of the phase-change material, the resistor being able to conduct a current for heating of the phase-change material to enable a transition from the first phase to the second phase, the phase-change material being a composition of formula  $Sb_aTe_bX_{100-(a+b)}$  with a, b and  $100-(a+b)$  denoting atomic percentages satisfying  $1 \leq a/b \leq 8$  and  $4 \leq 100-(a+b) \leq 22$ , and X being one or more elements selected from Ge, In, Ag, Ga and Zn.

2. An electric device as claimed in Claim 1, wherein the phase-change material comprises at least 10 % and less than 22 % Ge.

3. An electric device as claimed in Claim 1, wherein the first contact area is smaller than or equal to the second contact area, the first contact area having a characteristic dimension d, d being larger than  $6 \cdot a/b$  where d is in nm.

4. An electric device as claimed in Claim 3, wherein d is larger than  $3 \cdot a/b$  where d is in nm.

5. An electric device as claimed in Claim 1, wherein the phase-change material of the resistor is in direct contact with a crystallization layer for expediting the transition from an amorphous phase to a crystalline phase.

6. An electric device as claimed in Claim 5, wherein the crystallization layer has a thickness smaller than 100 nm.

7. An electric device as claimed in Claim 5, wherein the crystallization layer is in direct contact with the first contact area and/or in direct contact with the second contact area.

8. An electric device as claimed in Claim 1, wherein a first conductor electrically connected to the first contact area, a second conductor electrically connected to the second contact area and the resistor constitute a memory element, and the body comprises:

- 5 - an array of memory cells, each memory cell comprising a respective memory element and a respective selection device, and
- a grid of selection lines,
- each memory cell being individually accessible via the respective selection lines connected to the respective selection device.

10

9. An electric device as claimed in Claim 8, wherein:

- the selection device comprises a metal oxide semiconductor field effect transistor having a source region, a drain region and a gate region, and
- the grid of selection lines comprises N first selection lines, M second selection
- 15 lines, N and M being integers, and an output line,
- the first conductor of each memory element being electrically connected to a first region selected from the source region and the drain region of the corresponding metal oxide semiconductor field effect transistor, the second conductor of each memory element being electrically connected to the output line, a second region of the corresponding metal oxide
- 20 semiconductor field effect transistor which is selected from the source region and the drain region and which is free from the first region, being electrically connected to one of the N first selection lines, the gate region being electrically connected to one of the M second selection lines.

- 25 10. An electric apparatus comprising a processor, a memory coupled to the processor, and a display coupled to an output of the processor, wherein the memory comprises an electrical device as claimed in Claim 1.

ABSTRACT:

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(92)

The electric device (1, 100) has a body (2, 101) with a resistor (7, 250) comprising of a phase-change material able to be in a first phase and able to be in a second phase. The resistor (7, 250) has a surface with a first contact area (5, 132) and a second contact area (6, 272), and has an electrical resistance between them. The electrical resistance has a first value when the phase-change material is in the first phase and a second value when the phase-change material is in the second phase. the second value is different from the first value. The phase-change material comprises Sb, Te and X being one or more elements selected from Ge, In, Ag, Ga and Zn in the ratio  $Sb_aTe_bX_{100-(a+b)}$ . Here, a, b and  $100-(a+b)$  denoting atomic percentages with  $1 \leq a/b \leq 8$  and  $4 \leq 100-(a+b) \leq 22$ . The electric device (1, 100) further comprises a first conductor (3, 130) electrically connected to the first contact area (5, 132), and a second conductor (4, 270) electrically connected to the second contact area (6, 272). The first conductor (3, 130), the second conductor (4, 270) and the resistor (7, 250) are able to conduct a current for heating of the phase-change material to enable a transition from the first phase to the second phase.

Fig. 5

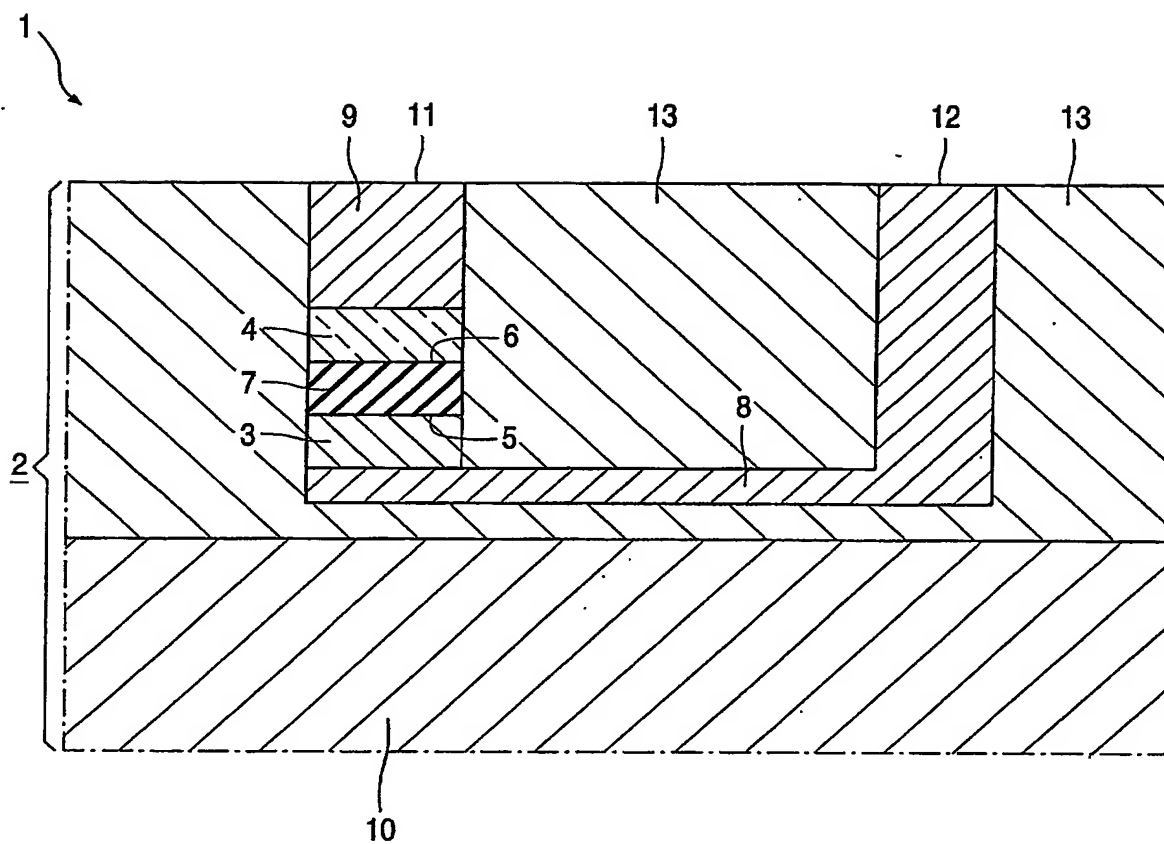


FIG. 1

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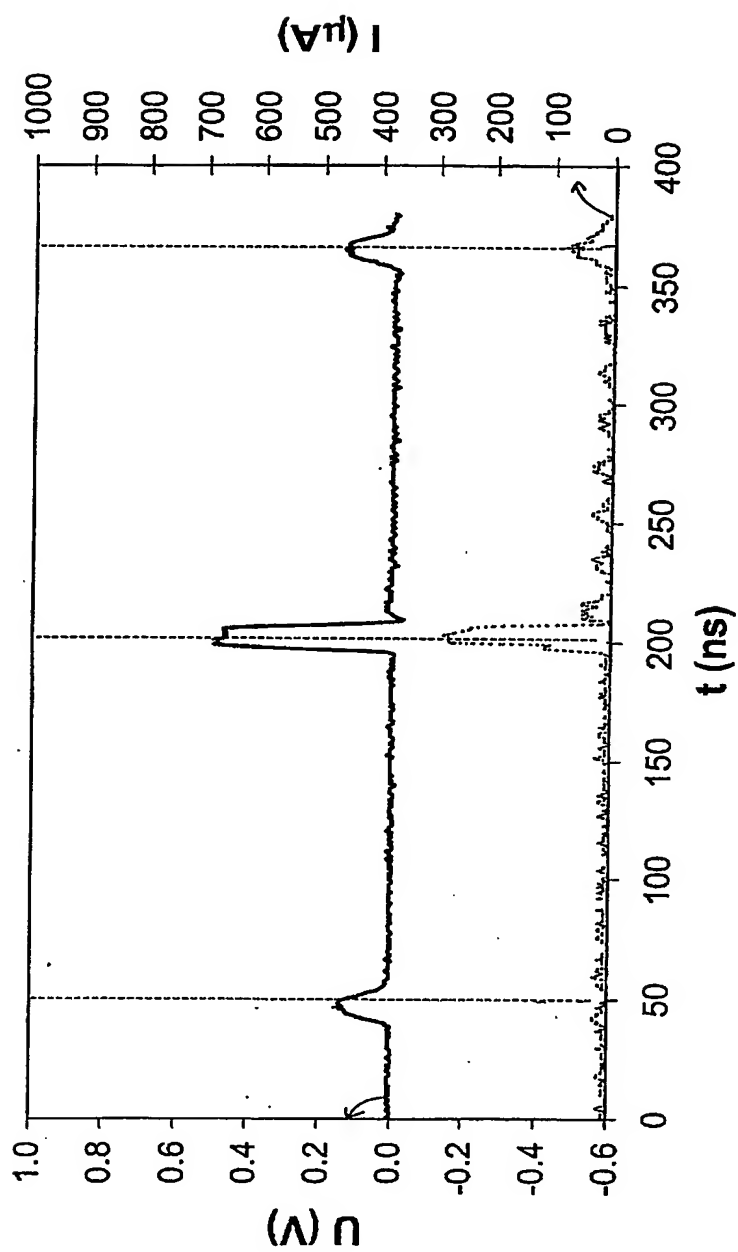


FIG.2A

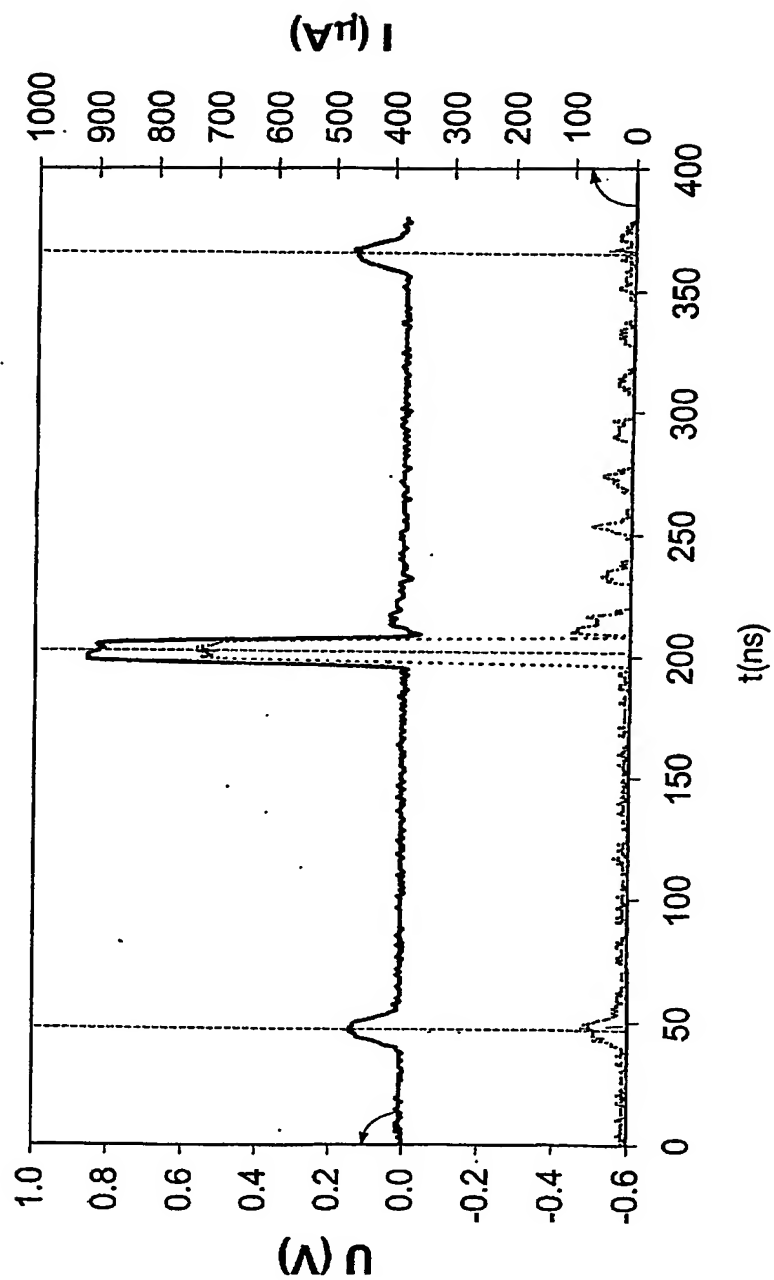


FIG.2B

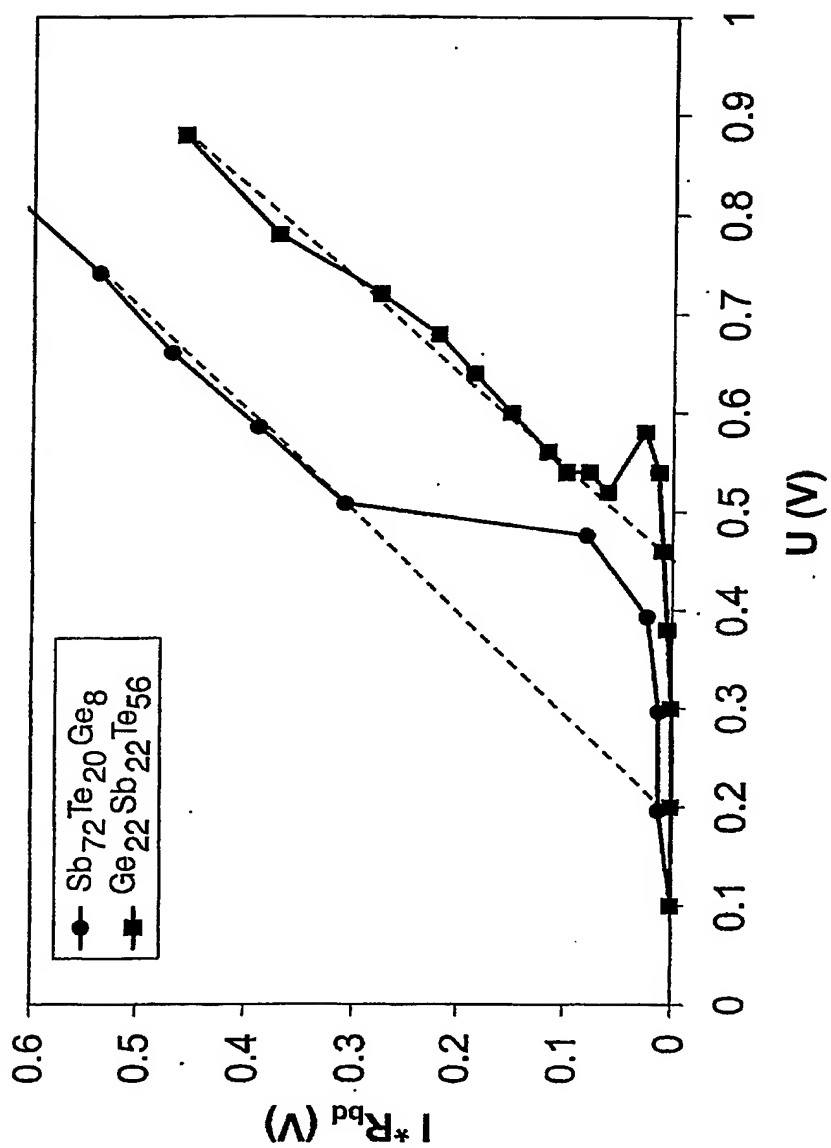


FIG.3

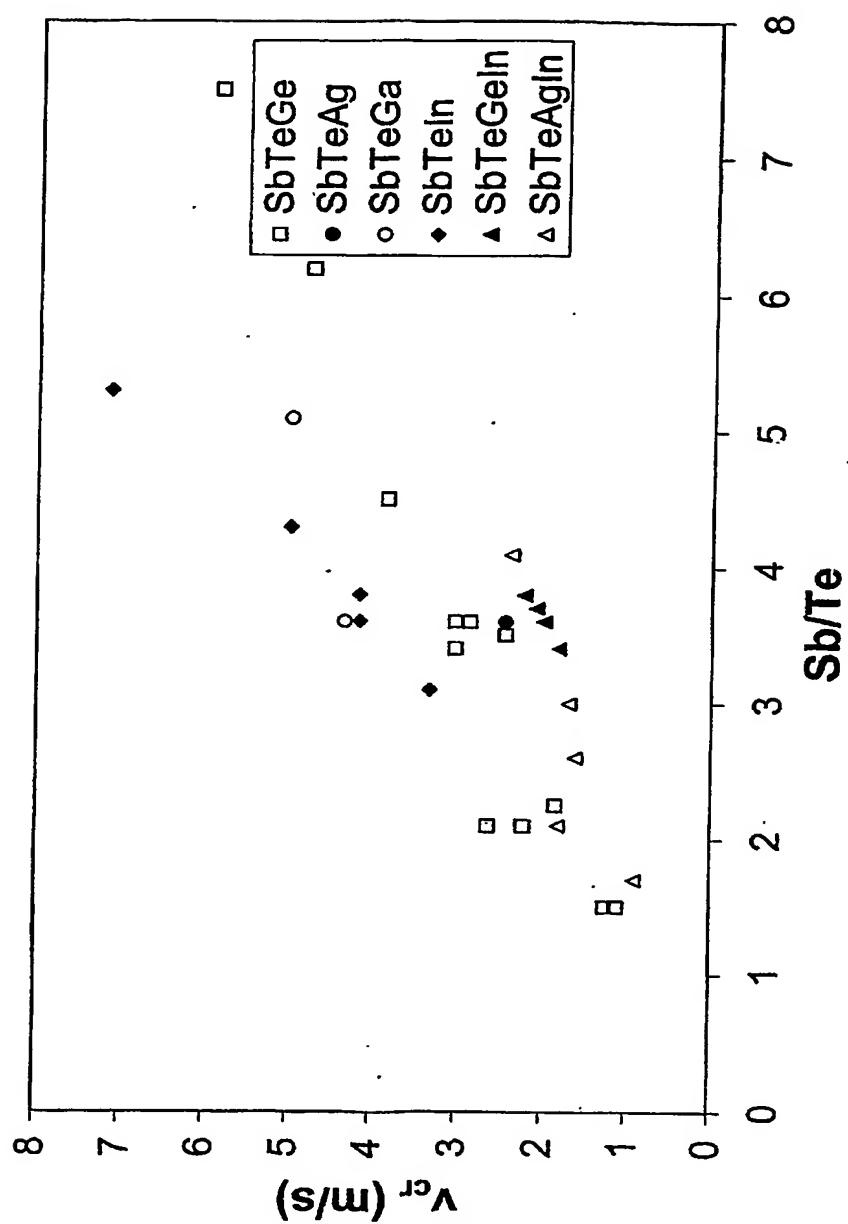
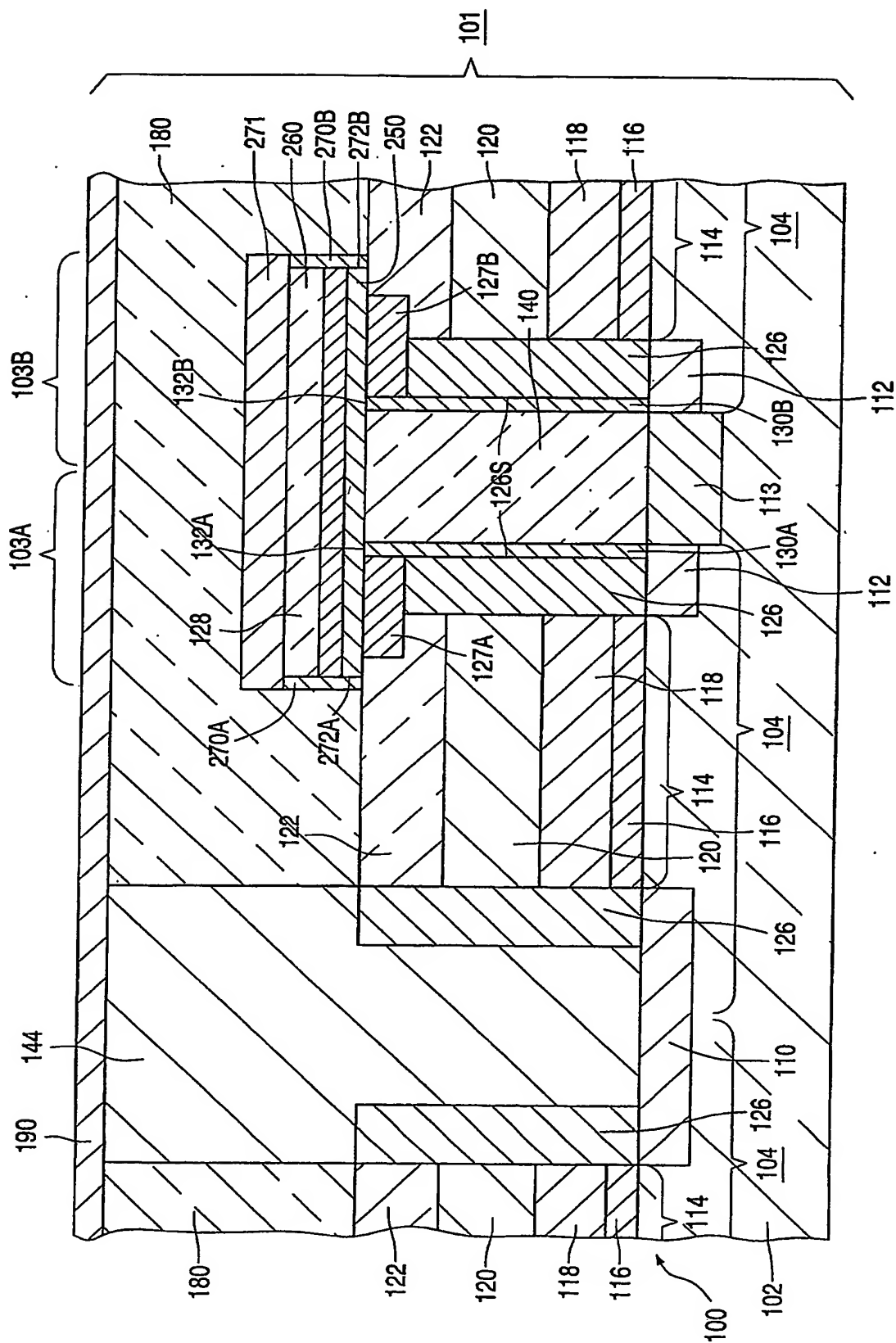


FIG.4



**FIG. 5**

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